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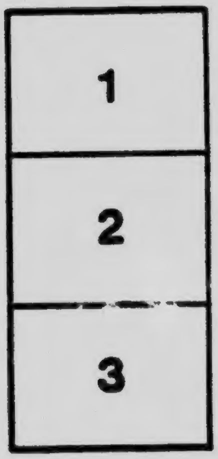

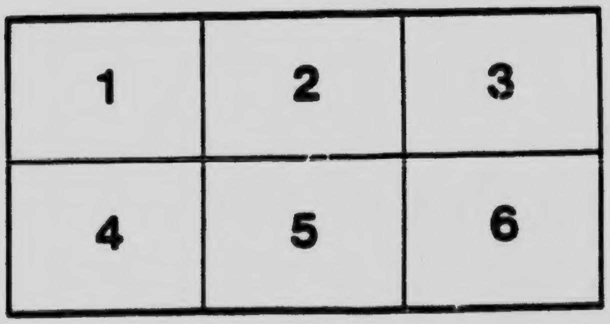

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SIMULTANEOUS VARIATIONS IN SOLAR RADIATION AND SPECTROSCOPIC DETERMINATIONS OF THE SOLAR ROTATION

AND

SPECTROSCOPIC MEASUREMENTS OF THE SOLAR ROTATION AT THE EQUATORIAL LIMBS AND AT POINTS MIDWAY BETWEEN THEM AND THE CENTRE OF THE SOLAR DISC

BY

RALPH E. DeLURY,
DOMINION OBSERVATORY, OTTAWA

SIMULTANEOUS VARIATIONS IN SOLAR RADIATION AND SPECTROSCOPIC DETERMINATIONS OF THE SOLAR ROTATION.

BY RALPH E. DE LURY

VARIATIONS in spectroscopic measurements of the rate of the sun's rotation have been ascribed by the writer to changes in haze between the sun and the earth or in their atmospheres[1]; and it has been suggested that simultaneous measurements of the intensity of solar radiation would exhibit corresponding fluctuations if changes in haze were in reality the cause of the variations. It is therefore desirable that measurements of rotation and radiation be made at the same time and place, along with observations of sky brightness and polarization which change with terrestrial haziness, in order that the nature of the variations may be more definitely interpreted. In the meantime the following examination reveals general similarity in the variations of the rates of radiation and rotation measured at different observatories.

Annual or semi-annual means of intensities of solar radiation at the surface of the earth, expressed as percentages of the general mean for each station, have been charted by H. H. Kimball[2] from 1883 to 1912, as follows: Montpellier, France, 1883-1900; Lausanne, Switzerland, 1896-1903; Warsaw, Russia, 1901-1905; Washington, D.C., and Mount Weather, Va., 1905-1912. From these charts the accompanying graph, 1891-1912, has been taken, using up to 1905 means of overlapping series of observations and this graph has been continued from 1912-1917 from the Washington solar radiation intensities published by Kimball in the numbers of the *Monthly Weather Review*, by taking half-yearly means of the a.m. values at 60° zenith distance and expressing these in terms of Kimball's means of a.m. values at 60° zenith distance for 1905-1910. The graph shows marked depressions in 1902-3 and 1912-13, due to general terrestrial haziness produced by the volcanic eruptions in the West Indies in 1902 and at Katmai, Alaska, in June, 1912, and smaller depressions in 1907 and 1915-17, due possibly, to haziness accompanying the solar activities, and the corresponding terrestrial electro-magnetic effects.

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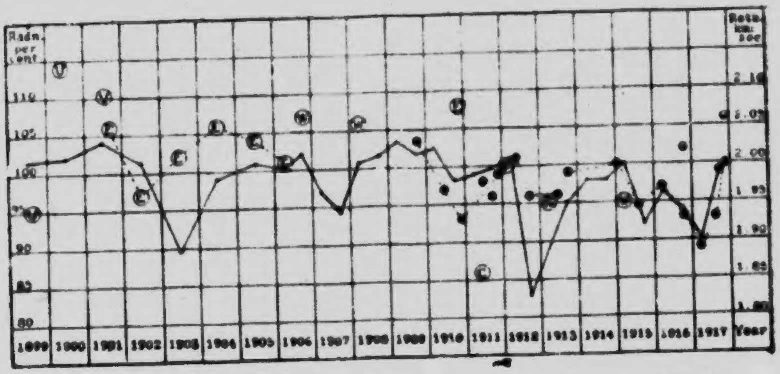
[1] *Journal* R. A. S. C., X., 201, and 343, 1916; *Astrophysical Journal*, XLIV., 177 and 198, 1916; also Oct., 1918.

[2] *Bulletin*, Mount Weather Observatory, V., 301, 1913.



Graph of solar radiation percentages; with spectroscopic measurements of the equatorial rate of the solar rotation, as follows: U, Upsala, Dunér; E, Edinburgh, Halm, 1901-6, and Storey and Wilson, 1910; W, Mount Wilson, Adams, 1906 and 1908, and St. John, Adams and Ware, 1914-5; C, Cambridge, England, Hubrecht; P, Pittsburgh, Schlesinger; K, Kodaikánal, Evershed and Royds; small circles, black (limb), and half black (midway centre to limb), Ottawa, DeLury.

Along with the graph of intensities of solar radiation are plotted measurements of the rate of rotation at the solar equator as determined by the displacements of the spectrum lines. Both sets of measurements are of course affected by local haziness and circumstances which may offset the general terrestrial conditions, yet nevertheless, it is apparent that general terrestrial haziness lessens the values of both: this is also seen in the following numerical statement:

Year	Radiation Percentages	Rotation km. per sec.	Observer	Observatory
1887·8·9	102	2.09	Dunér	Upsala
1899·0·1	102	2·05	"	"
1901·7	104	2·06	Halm	Edinburgh
1902·5	100 ±	1·97	"	"
1903·4	90 ±	2·02	"	"
1904·5	99 ±	2·06	"	"
1905·5	101	2·04	"	"
1906·3	101	2·01	"	"
1910·9	98	2·08	Storey and Wilson	Mount Wilson
1906·8	101	2·07	Adams	" "
1908·3	101	2·06	"	" "
1914·15	97 ±	1·95	St. John, Adams, Ware	
1909·8	102	2·04	DeLury	Ottawa
1910·5	100	1·97	"	"
1910·9	98	1·93	"	"
1911·7	100 –	1·98	" 2·01 | S. Plaskett	"
1912·4	100 +	2·01	" 2·01 "	"
1912·8	83 ±	1·96	" 2·00 "	"
1913·4	93 ±	1·96	" 1·99 " 1·98 H. Plaskett	"
1913·7	95	1·99	" (1·97) "	"
1915·1	100 –	2·00	"	"
1915·5	95	1·94	" 1·95 "	"
1916·3	96	1·97	"	"
1916·8	93	1·93	"	"
1917·2	90	1·89	"	"
1917·6	96	1·93	"	"
1917·8	98	1·98	"	"
1911·4	99	1·86	Hubrecht	Cambridge
1911·12	100–83	2·00	Schlesinger	Pittsburgh
1911·12	95 ±	1·95 ± ·1	Evershed and Royds	Kodaikanal
1913·2	90 ±	1·95 ±	" "	"

Means for Radiation Percentages 100 or over:

101 2·03

Means for Radiation Percentages less than 100:

95 1·97

Thus a drop of 6 per cent. from the average intensity of solar radiation is accompanied by a lessening of 3 per cent. in spectroscopic measurements of the rate of rotation at the sun's equator.

Dunér's high values of the rate of rotation of the sun were measured at times of high radiation. Halm's values show a drop in 1902 and 1903, ascribed by him to changes in the sun. It is probable that the haze produced by the volcanoes in the West Indies (May to October, 1902) affected his measurements, though he mentions precautions taken to avoid the effects of sky spectrum[1]. It is significant, however, that the means of his August observations in 1901 and 1902 were respectively (for departures from the equator of 8° and under), 2.08 km. per sec., 4°.3, 29 observations, and 1.88 km. per sec., 4°.6, 6 observations; also, that (for departures from the equator of 10° or less) in 1902, for the interval, Feb. 12-April 29, 24 observations yielded a mean of 2.02 km. per sec., average angle 4°.9, while for the interval, June 30-Sept. 19, 20 observations yielded a mean velocity of 1.96 km. per sec., average angle 5°.0, respectively before and after the May and June eruptions in the West Indies. The Mount Wilson measures show agreement also with the radiation values, being higher in 1906 and 1908 than in 1914-15. For the period 1909 to 1917, the writer's measurements of rotation[2] fluctuate with the variations in H. H. Kimball's measures of radiation at Washington, D.C. It is reasonable to suppose that the writer's values in 1912.8 were lessened by the residual haziness from Katmai, it being impossible to make suitable observations during July, August and September of that year owing to this cause. It is probable also that the very low values obtained by Evershed and Royds during the latter part of 1912 and the still low values in the first five months of 1913 were caused by the haze produced by Katmai. Local conditions probably account for the exceptional values obtained by Storey and Wilson and by Hubrecht. The Upsala and Edinburgh values are high relatively to most of the other measures, possibly because they were measured in the red part of the spectrum, where the effect of haze appears to be not so great as in the more refrangible part of the spectrum.

[1] *Trans. Royal Soc. of Edinburgh*, XLI., Part. 1, 89, 1904.

[2] On the accompanying chart at 1916.8 and 1917.9 are shown two half-blackened circles which indicate the values of rotation determined from spectra of points half way out from centre to limb along the equator, while the limb values for the same dates are denoted by the black circles; the latter values are smaller than the midway values, probably due to blended spectrum of haze, as explained in the note following the present one in this JOURNAL.

On the whole the synchronization of the variations in measurements of solar radiation and rotation is fairly good, considering that momentary local conditions may affect either observation profoundly. It is important that both observations be made precisely simultaneously at the same place. From such observations it may be possible to deduce relationships such that the variations in solar radiation (due to haze) could be computed from the rotational displacements of spectrum lines,—particularly those lines which are most lessened by the blending with the spectrum of haze. At the present time there is no sound reason for believing that the variations in the spectroscopic measurements of the rate of the sun's rotation indicate real solar phenomena.

Dominion Observatory,
  Ottawa, Canada,
    October, 1918.

SPECTROSCOPIC MEASUREMENTS OF THE SOLAR ROTATION AT THE EQUATORIAL LIMBS AND AT POINTS MIDWAY BETWEEN THEM AND THE CENTRE OF THE SOLAR DISC.

BY RALPH E. DE LURY.

BY employing a pair of double-tongued reflecting prisms[1] over the slit of the solar spectrograph, and by means of two other reflecting prisms (W and E in the diagram) directing to these prisms beams of light from within the limbs of the solar disc at points diametrically opposite, it is possible to photograph simultaneously two pairs of strips of limb spectra with a strip of spectrum from the centre of the solar disc,—and also, if desired, two strips of spectra from points symmetrically above and below the centre of the disc. Such a system of prisms has been employed at Ottawa since 1913. In many of the observations a tube containing iodine vapour is placed over the tongued prisms in such a way that the beams of light from the points above and below the centre of the solar disc pass through the iodine vapour (which is maintained at a constant pressure of 250 mm., and temperature of 50°-80° C., thus producing a standard iodine absorption spectrum), while the beam of light from the centre of the disc is protected from the iodine vapour by a thin-walled brass tube of 3 mm. bore, which is held in the centre of the iodine tube and is pressed tightly against its plate glass ends. During the past two years this apparatus has been improved further by mounting prisms MW and ME (see diagram) so that they cut out one strip of spectrum from each limb and supply instead strips of spectra from points about midway between the limbs and the centre of the disc. A convenient arrangement has also been installed for obtaining arc (or spark) spectra through the MW and ME prisms.

[1] De Lury, Report of the Chief Astronomer, Ottawa, 1911, p. 290.

Also, prisms at the S and N limbs direct beams of light to two more prisms mounted over the slit above and below the double-tongued prisms, making possible the photography of two extra strips of limb spectra. A mm. comb placed over the slit insures a spacing of 1 mm. from the middle of one strip of spectrum to the middle of the next strip. It is thus possible to photograph simul-

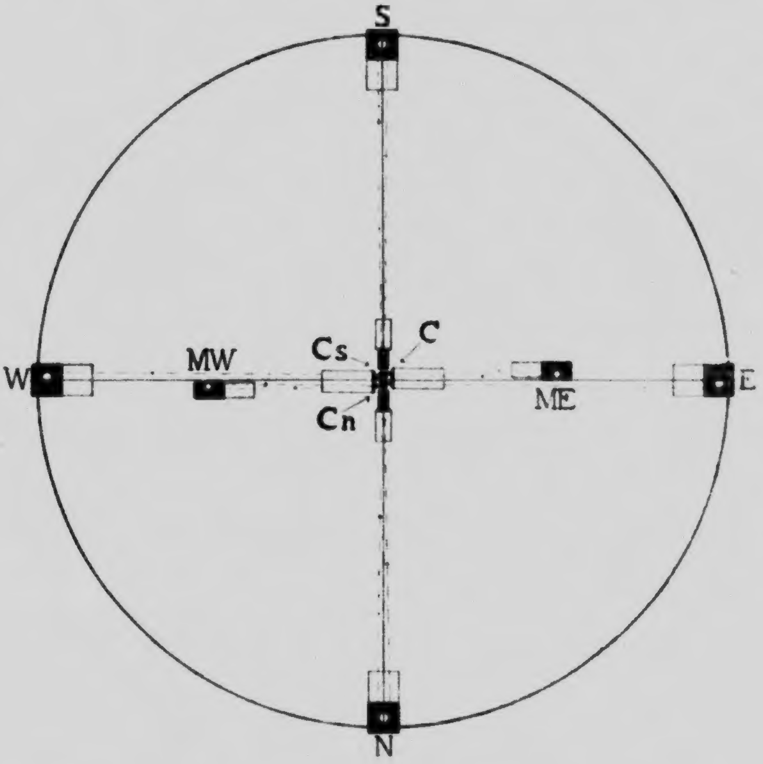


Diagram representing the solar disc (circle 228 mm. in diameter), and the arrangement of reflecting prisms whose diagonal surfaces (in heavy black) direct beams of light from various points on the solar disc (white circles on black at N, E, S, W, MW and M E) to the tongued prisms which redirect the light through the spectrograph-slit which lies under the NS diameter at the centre.

taneously nine strips of spectra adjacent to one another in the following order, namely, a strip from each of the following sources: S (south limb), Cs (3 mm. south of the centre of the solar disc, with or without iodine absorption), ME (midway between centre and east limb; or electric arc), W (west limb), C (centre of solar disc), E (east limb), MW (midway between centre and west limb; or electric arc), Cn (3 mm. north of the centre of the solar disc, with or without iodine absorption), N (north limb). By rotating the spectrograph, any four quadrantal points may be observed at the limb instead of the N, E, S, W points.

This arrangement of reflecting prisms makes possible the simultaneous investigation of many problems relating to the determinations of the character and wave-lengths of solar and arc spectrum lines from various sources. One of these is the determinations of the equatorial rate of the solar rotation from the spectrum line-displacements at the limbs and at points midway between them and the centre of the disc, from photographs of the spectra made at the same time. These determinations will furnish an independent test of the presence of a blended spectrum of haze, evidence of which the writer has found in other ways[1]; for the limb spectrum is weaker and its lines more weakened relatively to the centre spectrum or the haze spectrum than is the case with the spectrum from the midway point, and consequently the blended spectrum of haze will lessen the values of the rate of rotation as determined from the limb line-displacements probably more than it lessens the values derived from the line-displacements in the spectra of the midway points. Many such photographic observations of the limb and midway spectra have been made, and those measured up to the present indicate a decided tendency to yield larger values for the rate of rotation from the midway spectra than for the limb spectra. Only an outline of these results will be given here.

To determine the line-displacements from the spectra indicated in the diagram, MW-ME and W-E, it is necessary to determine very accurately the tilt of the spider thread of the micrometer to the spectrum lines. This may be done by measuring the displacement of the solar or iodine spectrim lines in Cs relatively to those in Cn, or possibly in N relatively to S. An error in determining this tilt will be twice as great for the displacement in MW-ME as for the displacement in W-E, and of opposite sign. This will cause an error in the derived rates of rotation which will be four times greater in the midway values than in the limb values. The limb measurements are found to be much more stable than the midway measurements, particularly when only a few lines are measured for determining the tilt of the micrometer line to the spectrum lines. The measurements of 75 plates taken during various degrees of haziness yielded the following values of the rate of the solar equatorial rotation from the limbs and the midway points:

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[1] This JOURNAL, Vol. X, pp. 201 and 343, 1916; and November, 1918 (preceding this). Also, *Astrophysical Journal*, XLIV, 177 and 198, 1916; and Oct., 1918.

Number of plates.	λ	Limb Rotation km. per sec.	Midway Rotation, km. per sec.	Difference, km. per sec.
56	5600	1.885	1.994	0.109
14	5200	1.913	2.005	0.093
5	3950	1.996	2.061	0.066

On the plates at λ 5200, lines of intensities 1 to 30 were measured with the following results relating to velocity and line-intensity:

Mean Intensity	2.9	22	Difference.
Number of lines	9	3	km. per sec.
Velocity, km. per sec., Limb.	1.900	1.954	0.054
Velocity, km. per sec., Midway	1.997	2.023	0.026

If, as has been suggested (*loc. cit.*), the magnitude of the difference in velocity determined from groups of weak and of strong lines be taken as a measure of the magnitude of the effect of blended spectrum of haze, it would seem (as expected) that the effect is greater on limb spectra (difference, 0.054) than on midway spectra (difference, 0.026), and as a result the rate of rotation derived from the midway spectra (2.005) is greater than that derived from the limb spectra (1.913).

It is desirable that many more measurements be made, and that the law of change in passing out to the limb of the sun be investigated; and it may be that the value of the solar rotation, unaffected by blended spectra, may be inferred therefrom. It may be noted also, that such investigations will enable one to make distinctions between Adams' level hypothesis and that of blended spectra in explaining the differences in velocity,—such distinctions as have already been made (*loc. cit*) from other considerations; and furthermore, such investigations will enable one to determine at the same time the changes in the wave-lengths of the spectrum lines in passing from the centre of the solar disc to the limbs.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
OCTOBER, 1918.